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EVALUATION AND PLANNING OF UNDERGROUND SPACE RESOURCES IN COMPLEX BUILT -UP ENVIRONMENT FROM THE PERSPECTIVE OF MULTI-DIMENSIONAL VALUES-- TAKING THE CORE AREA OF THE CAPITAL IN BEIJING AS AN EXAMPLE

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Abstract: In order to effectively support the planning and decision-making of underground space and realize the fine control and guidance of underground space utilization in complex built-up environment, this paper takes the Core Functional Area of the Capital, which has the highest density and the most complex urban environment in Beijing, as an example to explore the resource evaluation methods of underground space in built-up area. Concerning the characteristics of the built-up area, both the stock and incremental resources of underground space are taken into account. The paper establishes a comprehensive evaluation framework for the development potential of underground space resources covering seven value dimensions, including economic value, social demand, ecological environment, historical protection, disaster prevention, spatial layout and functional facilities, and comprehensively sorts out the influencing factors and quantitative indicators in each value dimension, so as to carry out the quantitative evaluation of the underground development potential accurate to plot. The paper hopes to effectively support the zoning and planning of underground space and provide technical support for the fine management and scientific utilization of underground space resources in high-density built-up areas.

Keywords: multi-dimensional value; high-density built-up area; underground space; resource evaluation; Planning & control

1. INTRODUCTION

Urban development is a dynamic and three-dimensional process. With the continuous renewal of land use, the construction space is correspondingly expanded upward and downward. Underground space resources have gradually become an important way to realize urban function and space optimization [1]. How to effectively identify underground space resources and scientifically judge thevalue and potential of underground space development and utilization is an important premise to promote the scientific and orderly utilization of underground space resources. The existing studies on the evaluation of underground space resources mainly focus on the incremental resources of underground space [2] from

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the perspective of eco-geological conditions, which pays less attention to the stock resources of underground space. Meanwhile, the current evaluation of underground resources mainly aims at new areas, which is not suitable for built-up areas with a large number of existing buildings, structures and historical & cultural heritage. In view of the above problems, this paper takes the Core Functional Area of the Capital as an example, to explore the identification and planning decision methods of underground resources in highly built areas, taking into account both the development and renewal needs of underground space. The paper will comprehensively analyze the influencing factors of social, economic, ecological, historical and security conditions to support the fine management and zoning of underground space in complex-built environment.

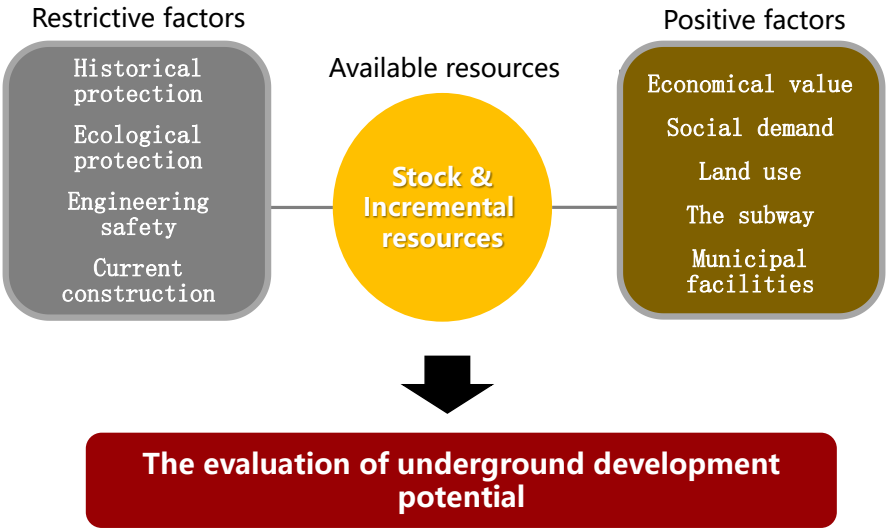

Figure 1. *Diagram of underground space resource assessment and planning model in high-density built-up area*

2. OVERVIEW OF THE CORE FUNCTIONAL AREA OF THE CAPITAL

The Core Functional Area of the Capital has a total area of 92.5 square kilometers and a population of about 1.7 million, which faces multiple needs such as the protection of the old city, the improvement of the living environment, the optimization of the administration environment and the promotion of urban vitality. Meanwhile, the area also has a high degree of underground space development, where more than 70% of the construction land (excluding roads, green space and water) contains underground development. How to effectively identify the available resources of underground space and appropriately guide development of aboveground and underground space is the key to the sustainable development of the built-up area.

3. IDENTIFICATION OF UNDERGROUND SPACE RESOURCES

In a broad sense, underground space is a comprehensive concept, which contains not only space resources, but also groundwater, energy, rock & soil and etc. This paper mainly involves space resources, which can be preliminarily divided into stock resources and incremental resources in terms of development status.

3.1. Stock resources

Underground stock resources are built spaces that can be used for other purposes after certain transformation. The study considers that the main factors affecting the reutilization of underground stock resources include construction time, building area, underground floors, functional types, etc. A comprehensive analysis was conducted on the underground stock resources within the core area. The study finds that the time of construction is of critical effect as frame structure is widely used in the underground space built after 2000, which has high spatial compatibility. At the same time, the spatial compatibility of the underground space also increases with the building scale, the number of floors and the functional types. By analysis, the stock resources of underground space built after 2000 with an area of more than 5000 square meters have higher potential for reutilization, which account for about 10% of the total amount and 54% of the building area (see Table 1). These stock resources are mostly multifunctional and of concrete frame structure, which makes it more suitable for flexible uses.

Table 1. *Classification and statistics table of underground space stock resources*

Type	amount	building area (10,000㎡)	Proportion of building area	Proportion of amount	Average building area (m^2)
General	4467	374.0	0.21	0.67	837.28
Better	1511	456.76	0.25	0.23	3022.91
High quality	663	962.4	0.54	0.10	14515.90
Total	6641	1793.18	1.00	1.00	2700.16

3.2. Incremental Resources

From the perspective of urban development conditions and land ownership settings, the incremental resources of underground space in high-density built-up areas are in close combination with the needs of urban renewal. The construction forms mainly include the coordinated construction of the aboveground and underground after demolition of original buildings, the reconstruction and expansion of underground space on the basis of the original buildings & structures, and the new underground projects (see Table 2), which can improve the utilization efficiency of land resources, improve the short board of urban functions, and improve the quality of urban environment on the ground.

Table 2. *Classification and statistics table of underground space incremental resources*

Classification	Resource utilization strategy
Demolish and rebuild	Through the coordinated utilization of ground and underground space, we can improve urban functions and supplement the shortcomings of public facilities.
Reconstruction and expansion	Through the reconstruction and expansion of underground space or adding connectivity on the basis of the original building, to improve the efficiency and functional use of underground space.
New underground projects	By building underground facilities such as parking lot or municipal stations to addressing the issue of insufficient construction space.

4. EVALUATION OF UNDERGROUND SPACE RESOURCES

The development potential of underground space resources is closely linked with the development needs of aboveground. Therefore, the evaluation of underground space resources should take into account various constraints and driving conditions both aboveground and underground, from the economic, social, ecological, historical, security and other dimensions.

4.1. Economic value

The economic value is an important factor to promote the development and utilization of underground space. The economic value of underground space is often positively correlated with land value, and is also affected by spatial location, functional use, and the number of underground floors [4]. Floor utility ratio is widely used to evaluate the three-dimensional value of land. Through the investigation of typical cases in the core area, the study finds that the average floor utility ratio of the underground floor is generally about 60%. In case of direct connection with the subway, the commercial rent price of the underground floor can reach 80% of the aboveground, that is, in addition to the spatial location and land uses, the subway connection also has a significant role in improving the economic value of the underground space. Therefore, in the process of judging the economic value of underground space, the study adopts the floor utility ratio method and takes the first floor of underground space as the evaluation object. Concerning whether it is located in the key functional area or connected with the subway, differentiated floor utility ratio (see Table 3) is adopted to evaluate the commercial rent of the corresponding underground space and form the economic value map (see Figure 2).

Table 3. *The floor utility ratio of the first underground floor in the Core Area of the Capital*

Functional use	Key functional area		General area	
	No subway connection	Connected to the subway	No subway connection	Connected to the subway
Commercial facilities	0.6	0.8	0.5	0.6
offices	0.5	0.6	0.4	0.5
residence	0.3	0.3	0.2	0.2

Note: *The specific indicators are summarized according to the investigation of typical projects in the core area.*

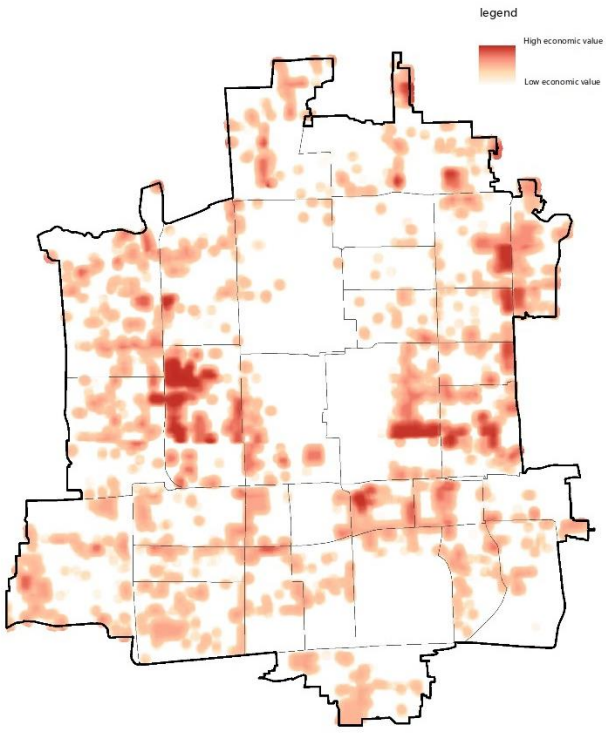

Figure 2. *Economic value assessment of commercial underground space in the Core Area of the Capital*

4.2. Social demand

High-density built-up areas tend to have a high concentration of people, so the social attributes of the users, their willingness and experiences, are important factors to the social needs of underground space [5] which are also closely related to the crowd concentration and demand. The study focuses on the social demand for underground space of various groups of people including residents, employees, shoppers and etc. A questionnaire survey of about 400 copies is carried out, using the Likert scale to analyze the demand level of different groups. Among them, the demand of shoppers is the highest, with an average of 4.0 (full score of 5.0), which includes shopping, cinema, video games and other entertainment activities. The demand of employees is relatively high, reaching 3.6 on average, mainly involving leisure activities such as exhibition, community activities, dining, fitness, reading in bookstores and etc. The demand of residents is relatively low, about 3.2, mainly involving community activities and convenient service. The social demand of the underground space is comprehensively evaluated in combination with the distribution density of various groups and their demand level (see Table 4), in which the shopping group is set as 1 (the demand score is 4), the employee group is 0.9 (3.6/4), and the residential group is 0.8 (3.2/4). Overall, there is a high correlation between the social demand for underground space and the distribution of economic value (see Figure 3).

Table 4. *Evaluation of underground space needs of various groups of people*

Type of group	Demand level	Distribution density		
		High (person/ha)	Medium (person/ha)	Low (person/ha)
Shopping group	1	150	100	80
Employee group	0.9	200	150	80
Residential group	0.8	120	100	60

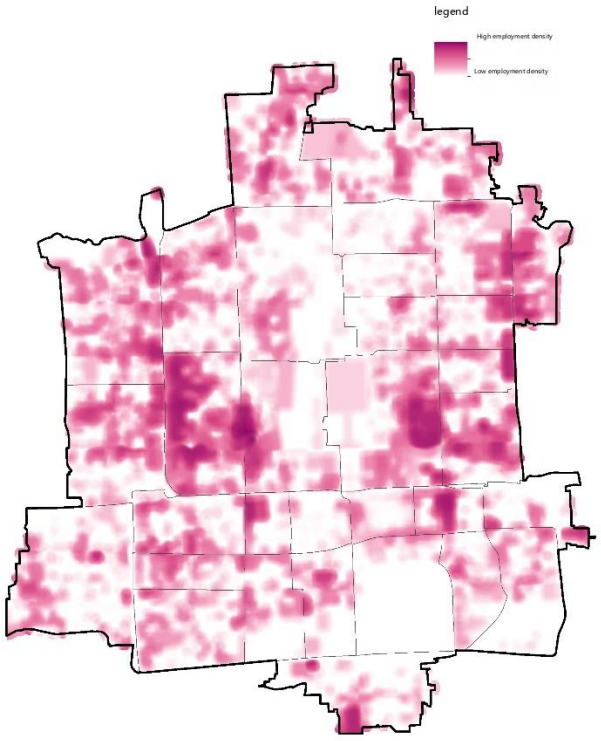

Figure 3. *Distribution of social needs of underground space for employed people in the Core Area of the Capital*

4.3. Ecological protection

The development and utilization of underground space should coordinate with the ecological environment so as to reduce the cost and safety risk. The ecological factors related to the development and utilization of underground space mainly include green space, farmland, river, groundwater, etc. In areas with important ecological value such as ecological protection area, important river and lake system, underground drinking water resources, the development and utilization of underground space shall not be carried out except for necessary infrastructure construction. Meanwhile, green space, ordinary farmland and water area can be moderately developed and utilized after meeting relevant environmental protection requirements. The impact of groundwater on underground space development involves project cost, groundwater pollution, water infiltration and corrosion, etc. Therefore, a suitable vertical construction scope of underground space should be adopted by referring to the groundwater level and the distribution of confined aquifers, so as to reduce the interference to the hydrogeological environment.

4.4. Historical & Cultural protection

The development and utilization of underground space should not only respect and protect all kinds of underground historical relics, but also avoid the impact and destruction of ground cultural and historical heritages. The core area has the richest historical and cultural resources in Beijing, where the protection of historical heritages and the control of building height significantly increase the demand for underground space development. On the one hand, the underground development should be moderately controlled according to the requirements of various historical protection areas. On the other hand, the role of underground space in historical preservation and cultural display should be encouraged by putting some functions or facilities underground for better restoration of traditional historical features on the ground. Meanwhile, underground space can also be used as cultural sites such as museums, exhibitions or other cultural display areas.

4.5. Risk protection

In highly built environment, the risk factors of underground space are very extensive. Among them, geological risks, such as active faults, sand liquefaction, karst collapse and other geological hazard areas should be avoided especially for high-intensity underground development. Current underground buildings, subway, gas pipelines and other infrastructures should be ensured a certain safety distance to avoid the risk of collapse, explosion and other disasters caused by adjacent underground projects. Attention should also be paid to the impact of extreme weathers, such as waterlogging in underground space caused by extreme rainstorms [6][7]. Compared with other areas in Beijing, the geological conditions of the core area are relatively suitable. The risks of underground engineering and waterlogging are main factors affecting the development and utilization of underground space. The study comprehensively considers the groundwater level and the burial depth of underground structures to analyze the areas with higher risk of anti-floating and infiltration. By delimiting the protection scope of the subway and underground pipelines, "unforeseen" engineering risks can also be avoided to some extent.

4.6. Spatial layout

The demand for underground space development is usually affected by spatial factors such as land use, density, space shortage and aggregation of public activities. In general, commercial & business land often has higher demand for underground development than that of residential & public service land, and the higher the intensity or density of above-ground development, the greater the demand for underground space development and utilization [8][9]. Meanwhile, central areas with strict the control of above-ground construction often have more demand for underground development [10]. The study comprehensively takes into account the spatial factors of central location, development intensity, aboveground control requirements, urban function aggregation (whether it is located in key functional or business areas) to evaluate the spatial demand of underground space development and utilization.

4.7. Functional facilities

The development and utilization of underground space is also affected by the construction of rail transit and various municipal facilities such as transportation, public service, disaster prevention, safety

facilities and etc. Among them, rail transit has the most prominent impact as the closer to the rail station, the higher the potential demand for the development and utilization of underground space [11][12]. For example, the underground commercial facilities and public spaces in Beijing Central Business District are mainly concentrated within 300 meters around the rail station [13], and most of them are directly or indirectly connected with the rail station [14]. The areas where large public service facilities concentrated can provide services and transportation space through the overall construction of underground space. Municipal infrastructure, public parking facilities, bus stations and emergency shelters can also improve the improve the level of facility services through the use of underground space and release more open space on the ground [15]. The study comprehensively defines the areas where there is a demand for the construction of underground functional facilities, including land within 300 meters around new or renovated rail stations and land for planned facilities which can be integrated developed aboveground and underground to improve the efficiency of land resources.

5. COMPREHENSIVE EVALUATION OF DEVELOPMENT AND UTILIZATION POTENTIAL

The study integrates the influencing factors of underground space development and utilization in various dimensions, extracting quantitative indicators from aspects of contributing and restrictive conditions, to comprehensively evaluate the potential of underground space development (see Table 5). The contributing factors include the four dimensions of economy, society, space and facilities, with rent/land price, crowd demand, development intensity, spatial location, rail transit and public facilities as the main indicators. Restrictive factors include the three dimensions of ecological, historical and risk protection. The weighted superposition method is used to comprehensively evaluate the demand and constraint of underground space development and utilization [16].

Table 5. *Dimensions and influencing factors of underground space resource potential assessment*

	Major dimensions	**Classification**	**Main considerations**	**Evaluation grade**	**Value**
Contributing	Economic dimension	Land value	Land price * floor utility ratio of the first underground floor * coefficient	High, Medium, Low	1、0.5、0.2
		Commercial rent	Shop rent * floor utility ratio of the first floor * coefficient	High, Medium, Low	1、0.5、0.2
	Social dimension	social demand	Population density * demand index	High, Medium, Low	1、0.5、0.2
	Spatial dimension	Land use	Commercial & business, public facilities, residential land	High, Medium, Low	1、0.5、0.2
		Development intensity	Floor area ratio > 2,1< Floor area ratio ≤ 2, Floor area ratio≤ 1	High, Medium, Low	1、0.5、0.2
		Spatial location	Key functional & business areas, commercial centers, public centers, etc.	High, Medium, Low	1、0.5、0.2
		Space scarcity	Central location degree, height control	High, Medium, Low	1、0.5、0.2

	Facility dimension	Rail transit construction	Rail station distance: within 300m, 300-500m, beyond 500m	High, Medium, Low	1、0.5、0.2
			Passenger flow≥ 100,000/day, 50,000-100,000/day, < 50,000/day		
			Connectivity: direct connectivity, combination of entrances and exits, non-connectivity		
		Public service facilities	Large cultural and sports facilities or clusters	Yes, no	1、0.2
		Other functional facilities	Underground municipal facilities, transportation facilities, disaster prevention facilities	Yes, no	1、0.2
Restrictive	Ecological dimension	no construction	ecological protection area, important river and lake system, important farmland, underground drinking water protection area and etc.	The development and utilization of underground space other than necessary infrastructure will not be carried out In principle	
		Restrict construction	Green Park	Yes, no	0.2、1
			Ordinary farmland	Yes, no	0.2、1
			Groundwater reserves or confined aquifers	Yes, no	0.2、1
	Historical dimension	No construction	Protection area and class I control area of cultural relics	The development and utilization of underground space other than historical protection will not be carried out in principle.	
		Restrict construction	Within the core protection scope	The development and utilization of underground space shall not be carried out except for the necessary infrastructure, public service facilities and historical protection.	
			Outside the core protected area	Yes, no	0.2、1
			Underground cultural relics	Necessary archaeological investigation and exploration shall be carried out to encourage the in-situ protection and display of cultural relics.	

Security dimension	No construction	Within 200m on both sides of the active fault zone	The development and utilization of underground space should avoid this area in principle.	
	Restrict construction	Safety protection scope of subway or underground pipeline, old basement/underground pipeline intensive area, other geological risk areas etc.	Yes, no	0.2、1

6. DISCUSSION AND CONCLUSION

The development and utilization of underground space in highly built-up area is in great demand [17]. The establishment of a systematic evaluation method of underground space resources is an important way to support the sustainable development of the built-up area. The study explores the identification method of underground space resources and carries out quantitative evaluation of the potential for underground space development and utilization, covering multiple value dimensions such as economy, society, history, ecology, safety, space, and facilities to support refined underground space planning and control zoning. The study hopes to provide technical support for underground space planning decisions in highly built environment. The conclusions of the study are as follows:

The underground space resources in highly built-up areas should include both incremental and stock resources. The latter refers to underground space that has already been built but can carry other functions through renewal and renovation. Generally, underground spaces built with frame structure, relatively large building scale and multiple functions have relatively high compacity and potential for reutilization, and can be prioritized as stock resources of underground space.

The development and utilization of underground space in highly built-up areas are significantly positively correlated with land value, employment population density, rail connectivity, and agglomeration of urban functions. Usually, key functional or business areas, commercial centers, large transportation hubs, and cultural & sports centers are the key areas for underground space development and utilization.

The restrictive factors for the development and utilization of underground space in highly built-up areas mainly include sensitive ecological environment, historical protection requirements, engineering safety, and geological hazard risks. Underground space should be utilized to a limited extent while meeting relevant control requirements. Both horizontal and vertical protection and control range should be considered to ensure the safety.

The comprehensive potential of underground space development in highly built-up areas should be considered in terms of resource conditions, development motivation, and restriction requirements. In the absence of prohibited restrictive factors, the development and utilization of underground space should prioritize areas with high land value/rent, functional clustering, social demand and close connection to the subway, where the integrated development of aboveground and underground should be carried out to effectively improve the efficiency of urban space.

The study mainly summarizes and quantitatively evaluates the influencing factors of underground space in different value dimensions based on case investigation data and practical experience in the core area. It still needs to be verified and calibrated on a larger scale. At the same time, attention should be

paid to different types of underground resources such as groundwater resources, underground rock and soil resources, renewable energy, and their influence on the development and utilization of underground space, in order to effectively coordinate the protection and development needs and achieve sustainable development of underground space in highly built-up areas.

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